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Evaluating the energy utilization efficiency of Turkey's renewable energy sources during 2001

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Abstract

This study evaluates the energy utilization efficiency of Turkey's renewable energy sources (RESs) during 2001 by using energy and exergy analyses, giving a brief outlook on the utilization of RESs. Total energy and exergy inputs are calculated to be 3203.22 PJ and 3139.07 PJ, while renewable energy and exergy production values are determined to be 428.62 PJ and 395.68 PJ, respectively. Renewable energy is used in the Turkish conversion, residential–commercial and industrial subsectors. The energy and exergy efficiency values for the RESs of Turkey are found to be 49.86% and 24.14% in 2001, respectively. Besides this, total energy and exergy utilization efficiency values for those are obtained to be 45.02% and 24.96% in the same year, respectively. The present study has clearly indicated the necessity of the planned studies towards increasing renewable energy utilization efficiency in the subsectors studied and especially the critical role of policymakers in establishing effective energy-efficiency delivery mechanisms throughout the country. It is also expected that this study will fill a considerably large gap since it is the first attempt towards analyzing Turkey's renewable energy sources in terms of energy and exergy utilization efficiencies.

Keywords: Renewable energy; Energy efficiency; Exergy efficiency; Energy utilization; Exergy utilization; Sustainable development; Turkey

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Contents

Nomenclature

a	share of renewables in the total of each component (%)
q	quality factor of an energy carrier (–)
r	the renewable use by the residential–commercial sector in energy terms (kJ)
T	temperature (K)
W	shaft work, work (kJ or kJ/kg)

Greek symbols

δH	enthalpy content of a particular energy carrier (kJ/kg)
ε_1	first law efficiency (%)
ε_2	second law efficiency (%)

Indices

0	dead state or reference environment
c	component

co	cooking
f	fuel
o	overall
r	renewable
rc	residential–commercial
s	sector
sh	space heating
wh	water heating

1. Introduction

The importance of energy as an essential ingredient in economic growth, as well as in any strategy for improving the quality of human life is well established. The energy policy agenda has changed significantly since the days of the 1973 and 1979 oil crises. Currently, it is possible to identify three policy themes relating to the energy sector. These are as follows [1]: (a) the traditional energy policy agenda relating to security of energy supply; (b) concern about the environmental impact of energy, its production, transformation and use; and (c) the trend towards liberalization and the enhancement of competition in energy markets, notably in the electricity and gas sectors.

Developing countries have 80% of the world's population, but consume only 30% of global commercial energy. As energy consumption rises with increases in population and living standards, awareness is growing about the environmental costs of energy and the need to expand access to energy in new ways. Increased recognition of the contribution renewable energy (RE) makes to rural development, lower health costs (linked to air pollution), energy independence, and climate change mitigation is shifting RE from the fringe to the mainstream of sustainable development [2]. In this context, energy exploitation and utilization should be based on the sustainable development and better ecological environment in developing countries, so that we can attain the objective of coordinating the relationships among society, economy, energy and sustainable environment that meets the needs of the present without compromising the ability of future generations to meet their own needs [3].

Dincer [4] reported the linkages between energy and exergy, exergy and the environment, energy and sustainable development, and energy policymaking and exergy in detail. He provided the following key points to highlight the importance of the exergy and its essential utilization in numerous ways: (a) it is a primary tool in best addressing the impact of energy resource utilization on the environment; (b) it is an effective method using the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the design and analysis of energy systems; (c) it is a suitable technique for furthering the goal of more efficient energy-resource use, for it enables the locations, types, and true magnitudes of wastes and losses to be determined; (d) it is an efficient technique

revealing whether or not and by how much it is possible to design more efficient energy systems by reducing the inefficiencies in existing systems; (e) it is a key component in obtaining sustainable development; (f) it has a crucial role in energy policymaking activities.

The exergy of an energy form or a substance is a measure of its usefulness or quality or potential to cause change [5]. Exergy is defined as the maximum work, which can be produced by a system or a flow of matter or energy at it comes to equilibrium with a specified reference environment. Unlike energy, exergy is conserved only during ideal processes and destroyed due to irreversibilities in real processes [6]. A true understanding of exergy and the insights needed into the efficiency, environmental impact and sustainability of energy systems, are required for the engineer or scientist working in the area of energy systems and the environment [7].

To date, various studies [8–16] were performed to analyze Turkey's energy and exergy utilization efficiencies in the four subsectors, namely utility, industrial, residential–commercial and transportation sectors. However, any study conducted on the evaluation of energy utilization efficiency of Turkey's RE sources (RESs) using energy and exergy analyses has not appeared in the open literature.

The structure of the paper is organized as follows. The first section includes the introduction; Section 2 gives a brief outlook on the utilization of RESs in Turkey, while the methodology used is described in Section 3; Turkey's total input configuration and evaluating the energy utilization efficiency of Turkey's RESs are treated in Sections 4 and 5, respectively; the results obtained from this study are discussed and compared with the previous studies in Section 6; and the last section concludes.

2. A brief outlook on the utilization of renewable energy sources in Turkey

National and international bodies use a variety of definitions for RE. The RE Working Party of International Energy Agency set down the following definitions: "RE is energy that derived from natural processes that are replenished constantly. In its various form the sun, or from heat generated deep within the earth. Included in the definition is energy generated from solar, wind, biomass, geothermal, hydropower and ocean resources, and biofuels and hydrogen derived from renewable resources [17]."

In 2001, world total primary energy supply (TPES) was 420,190 PJ, of which 13.3%, or 56,594 PJ, was produced from RESs [17]. Due to its frequent non-commercial use in developing countries, solid biomass (wood) is by far the largest RES, representing 10.4% of world TPES, or 77.4% of global renewables supply. The second largest source is hydropower, which provides 2.2% of world TPES, or 16.4% of renewables. Geothermal is third largest RES and is much smaller, representing less than 0.5% of world TPES or 3.2% of renewables supply in the world. The contribution of new renewables (solar, wind and tide) to energy supply is still

very marginal, representing less than 0.1% of the world TPES, or 0.5% of renewables supply.

RE is accepted as a key source for the future, not only for Turkey but also for the world. Turkey has considerably high levels of RESs that could be part of the total energy network in the country. As for a brief historical development of RESs in Turkey [18], the first small hydroelectric power plant with a capacity of 88 kW was installed in Tarsus-Adana, Turkey in 1902. In the period of the Republic of Turkey, the utilization of hydroelectric power was initiated first in 1929 with the establishment of the Visera power plant with a capacity of 1 MW in the city of Trabzon. In the early 1960s, solar energy was realized as an alternative energy in Turkey, and some curious researchers and dissertation students began to be interested in the solar energy matter. The first national congress on solar energy was performed in 1975 in Izmir, Turkey. The inventorial works and chemical analyses of the hot springs and mineral waters started in 1962, while the investigations on geothermal energy in the country have gained speed in the 1970s. The first residential geothermal heat pump system (or ground-source heat pump system) was installed in a villa in Istanbul in 1998. Electricity generation through wind energy for general use was first realized at Cesme Altinyunus Resort Hotel (The Golden Dolphin Hotel) in Izmir, Turkey in 1986 with a 55 kW nominal wind energy capacity, while the first wind turbines started operating in early 1998. In Turkey, much effort has been put into biogas research and development projects since the 1960s and studies on energy forests began scientifically in 1980 with the fourth 5-Year development plan.

The share of RE in Turkey's TPES in 2001 was 428.62 PJ [19,20], with the majority of total RE supply from biomass and animal products, mostly solid biomass (wood), and some geothermal energy. In addition, hydro-electricity provided 19.53% of country's electricity production. The relative importance of renewables in TPES continues to decline as domestic coal production and natural gas imports rise steadily to satisfy rising electricity demand. However, there is a significant room for expanding RE use in Turkey, which has a large resource base of biomass, geothermal, solar and wind energy as well as hydro.

In 2001, Turkey TPES was 3194.90 PJ, while the share of RE in Turkey's TPES was 13.38% [21]. The majority of TRES is from solid biomass (wood) with 6.37% of Turkey, or 47.58% of total renewables supply. The second largest source is hydropower, which provides 2.96% of Turkey TPES, or 22.15% of renewables. Geothermal is the third largest RES representing 1.97% of country TPES, or 14.82% of renewables supply in Turkey, followed by biomass with 1.74% of Turkey TPES, or 12.99% of renewables and solar with 0.32% of Turkey TPES, or 2.41% of renewables, and share of wind energy is 0.02% in TPES, or 0.05% renewables supply in Turkey.

2.1. Biomass

Biomass is defined as any plant matter used directly as fuel or converted into other forms before combustion. Included are wood, animal materials waste, and

plant waste which includes wood waste and crops used for energy production [22]. Turkey's mainly RESs are biomass (wood, animal-plant waste) and hydro power. Biomass's contribution to TPES was 258 PJ in 2001, including 203.94 PJ from wood. The remainder of animal-plant waste was 55.67 PJ. The majority of RE supply is solid biomass, which is used almost exclusively in the residential–commercial sector for heating.

Considering the total cereal products and fatty seed plants, approximately 50–60 million tons per year of biomass and 8–10 million tons of solid matter animal waste are produced, and 70% of the total biomass is seen as possible to use for energy [23,24].

2.2. *Biogas*

Biogas technology has been known for a long time, but in recent years the interest in it has significantly increased especially due to the higher costs and the rapid depletion of fossil fuels, as well as their environmental considerations. In Turkey, the studies conducted on biogas energy were not so active between 1986 and 2001. Since then, some experimental studies on biogas energy have been conducted at the two universities, namely Ege University, Izmir and Selcuk University, Konya, Turkey. Based on a study performed by Acaroglu et al. [25], Turkey's annual animal waste potential is estimated to be about 11.81 million tons (dry material) with a biogas energy equivalent of 53.6 PJ.

2.3. *Wind*

Turkey's total theoretically available potential for wind power may be around 88,000 MW annually, with particularly attractive areas for wind located along Turkey's west coast and in the south east of the country. The utilization of wind energy in Turkey has increased since 1998 when the first wind power plant with a total capacity of 1.5 MW was installed. Up to date, three wind power plants were installed with a total capacity of 18.9 MW, while a wind power plant with a total capacity of 1.2 MW was to be commissioned in November 2003. Electricity produced from wind energy between 1998 and 2001 in Turkey amounts to 104 GWh [26].

2.4. *Solar energy*

Turkey is situated in a sunny belt between 36° and 42° N latitude and is geographically well situated with respect to solar energy potential. Residential and industrial consumption of solar energy in Turkey started in 1986 and 1988, respectively [27]. The direct use of solar heat is small, but growing rapidly. Turkey estimates that this contributed 10.32 PJ in 2001, more than seven times its level with 1.47 PJ in 1991 [12,14]. Among all the above solar thermal utilization methods, solar water heating has been and will have the greatest emphasis in Turkey, reaching a total annual production capacity of 1,000,000 m^2 [27].

2.5. Hydropower

In Turkey, the 546 hydroelectric power plant projects have been planned in order to develop the hydroelectric potential of rivers. Based on the studies conducted by the State Water Works (DSI) and the General Directorate of Electrical Power Resources Survey Administration (EIE), total installed capacity of Turkey's rivers is calculated to be 35,310 MW [24].

In 2001, the share of hydropower in electricity output reached 19.54%, representing an electric power of about 87.25 PJ. Turkey has an economic hydropower potential estimated at 483 PJ, of which almost two-thirds has not yet been exploited. Increased generation is expected to continue, with generation rising to almost 235 PJ in 2010 and 391 PJ in 2020 [12].

2.6. Geothermal

Turkey is located on the Mediterranean sector of the Alpine-Himalayan Tectonic Belt and has a place among the first seven countries due to the abundance of geothermal resources around the world. The share of its potential used is, however, only about 2–3%. Recently, the total installed capacity has reached 820 MW_t for direct use. An annual average of 23% growth of residence connections to geothermal district heating systems has been achieved since 1983 in the country, representing a decrease of 5% in the last 3 years [28]. The only operating geothermal power plant of Turkey is the Denizli-Kizildere geothermal power plant located near Denizli City in Western Anatolia with an installed capacity of 20.4 MW_e [29].

The contribution of geothermal energy to TPES was 63.23 PJ in 2001, including 60.32 PJ direct use of geothermal heat. The remainder was used to generate 3.20 PJ of electricity. Official forecasts predict significant increases in direct use of geothermal energy for heating to 192 PJ in 2010, as the government is working on legislation aiming to increase the use of geothermal energy [12,30].

3. Methodology used

Establishing and formulating the laws of thermodynamics for thermal systems goes back to around the year 1850. The method of exergy analysis has been applied to a wide variety of thermal and thermochemical systems. A particular thermodynamical system is the society, for example, of a country or a region [31]. Recently, there has been increasing interest in using energy and exergy analysis modeling techniques for energy-utilization assessments in order to attain energy saving, and hence financial savings. The energy utilization of a country can be evaluated using exergy analysis to gain insights into its efficiency [10]. Actually, only a few of such analyses are available. The first one was applied by Reistad to the US in 1970, published in 1975 [31,32], while the most comprehensive one in terms of years appears to be Ayres et al.'s analysis of the US between 1900 and 1998, published in 2003 [33].

Based on earlier studies conducted in this field by many authors, the approaches used to perform the exergy analyses of countries may be grouped into two types, namely Reistad's approach and Wall's approach, as denoted by Ertesvag [31]. The first approach considers flows of energy carriers for energy use, while the second one takes into account all types of energy and material flows (see Ref. [31] for more details). Reistad's approach was followed in the analyses of Finland [34], Canada [35], Brazil [36], Saudi Arabia [37], and the Organization for Economic Co-operation and Development (OECD) countries, non-OECD countries, and the world [38]. Besides this, the analyses of Sweden [39–41], Ghana (adapted from Ref. [31]), Japan [42], Italy [43] and Norway [44] used Wall's approach.

As for the studies performed on Turkey's sectoral (commercial, residential, industrial and transportation) energy and exergy analyses, to date, nine studies [8–16] were undertaken. Of these, eight [8,10–16] followed Reistad's approach [32], while the last one [9] utilized a methodology applied for quantitative determinations of patterns of energy use in industry based on a nation-wide survey to characterize the structure of overall energy use in the Turkish food, textile and cement sectors. Besides this, any studies focusing on the exergy analysis of TRESs have not appeared in the literature. The methodology used in this study for analyzing energy and exergy efficiencies of TRES is similar to that of Rosen and Dincer [10], who used Reistad's approach [32] with several minor differences.

4. Turkey's total input configuration

Turkey, with a population of 68,820,985 in 2001 on 800,000 km^2 of land, is located between 35°50′ and 42°06′ north latitudes and 25°40′ and 44°48′ east longitudes. Most of Turkey is in Asia. The far northwestern part of the country is in Europe and is separated from the rest of the country by the Dardanelles and Bospherous Straits and the Sea of Marmara [19,20].

In this study, the values for population, total energy and exergy production, consumption and renewables energy and exergy production in Turkey in 2001 are determined using the data given in Refs. [19,20]. These values are summarized in Table 1.

Energy and exergy inputs for 2001 according to energy carriers are illustrated in Table 2. As can be seen in this table, total energy and exergy inputs to the Turkish sector were 3203.51 and 3139.07 PJ in 2001, respectively. Of total energy input, 36.52% was produced in 2001, while the rest was met by imports. In 2001, of 11

Table 1
Population, total and renewables energy/exergy production and consumption values of Turkey in 2001

Population	Total energy consumption (PJ)	Total exergy consumption (PJ)	Total energy production (PJ)	Total exergy production (PJ)	Renewables energy production (PJ)	Renewables exergy production (PJ)
68,820,985	3203.22	3139.07	1169.45	1159.22	428.62	395.68

Table 2
Energy and exergy production and consumption values of Turkey in 2001

Energy carrier	Toe[a] (q)	Energy (Exergy)	Production		Consumption	
			(PJ)	(%)	(PJ)	(%)
Hard coal	0.61	Energy	60.09	5.14	281.47	8.79
	1.03	(Exergy)	(61.90)	(5.34)	(289.92)	(9.23)
Lignite	0.21	Energy	556.90	47.60	569.54	17.78
	1.04	(Exergy)	(579.17)	(49.96)	(592.32)	(18.87)
Asphaltite	0.43	Energy	0.56	0.05	0.56	0.02
	0.97	(Exergy)	(0.57)	(0.05)	(0.57)	(0.02)
Petroleum	1.05	Energy	111.96	9.57	1301.82	40.64
	0.99	(Exergy)	(110.84)	(9.56)	(1288.8)	(41.05)
Natural gas	0.91	Energy	11.81	1.01	621.5	19.40
	0.92	(Exergy)	(10.86)	(0.94)	(571.78)	(18.21)
Wood	0.3	Energy	203.94	17.43	203.94	6.37
	1.05	(Exergy)	(214.13)	(18.47)	(214.13)	(6.82)
Biomass	0.23	Energy	55.67	4.76	55.67	1.74
	1.05	(Exergy)	(58.45)	(5.04)	(58.45)	(1.86)
Hydropower	0.086	Energy	94.94	8.11	94.94	2.96
	1.00	(Exergy)	(94.94)	(8.19)	(94.94)	(3.02)
Geothermal	0.86	Energy	63.52	5.40	63.52	1.97
	0.29	(Exergy)	(18.34)	(1.58)	(18.34)	(0.58)
Solar	0.86	Energy	10.32	0.88	10.32	0.32
	0.93	(Exergy)	(9.59)	(0.83)	(9.59)	(0.31)
Wind	0.086	Energy	0.23	0.05	0.23	0.02
	1.00	(Exergy)	(0.23)	(0.05)	(0.23)	(0.02)
Total		Energy	1169.94	100.00	3203.51	100.00
		(Exergy)	(1159.02)	(100.00)	(3139.07)	(100.00)

[a] The upper values are conversion factor to tons oil of equivalent (toe) while the lower values are quality factor.

energy sources, petroleum had biggest share with 40.64%, followed by natural gas with 19.40%, lignite with 17.78%, and hard coal with 8.79%. RE source production was the second biggest production source after total coal production, providing about 36.63% of the total production in 2001 [45]. Turkey's RE and exergy productions were 428.62 PJ and 395.68 PJ, respectively. The share of RESs is shown in Table 3. It is clear from this table that biomass (wood, animal, vegetables wastes) had the biggest share with 259.61 PJ, followed by hydropower with 94.94 PJ, geothermal energy with 63.52 PJ, solar energy with 10.32 PJ and wind energy with 0.23 PJ.

5. Evaluating the energy utilization efficiency of Turkey's renewable energy sources

In 2001, of Turkey's renewables, 39.955% was used by the residential–commercial sector. The share of the utility (conversion) and industrial sectors was 9.04% and 0.24%, respectively, while the transportation sector made no use of renewable energy, as illustrated in Table 4.

Table 3
Energy and exergy production values for Turkey's renewables and total in 2001

Type of renewable energy sources (RESs)	Energy (Exergy)	Renewables production (PJ)	Share of RESs in total renewables production (%)	Share of RESs in Turkey's total production (%)	Share of RESs in Turkey's total consumption (%)
Biomass	Energy	55.67	12.99	4.76	1.74
	(Exergy)	(58.45)	(14.77)	(5.04)	(1.86)
Wood	Energy	203.94	47.58	17.43	6.37
	(Exergy)	(214.13)	(54.12)	(18.48)	(6.82)
Hydropower	Energy	94.94	22.15	8.12	2.96
	(Exergy)	(94.94)	(23.99)	(8.19)	(3.02)
Geothermal	Energy	63.52	14.82	5.43	1.98
	(Exergy)	(18.34)	(4.64)	(1.58)	(0.58)
Solar	Energy	10.32	2.41	0.88	0.32
	(Exergy)	(9.59)	(2.42)	(0.83)	(0.31)
Wind	Energy	0.23	0.05	0.24	0.96
	(Exergy)	(0.23)	(0.06)	(0.02)	(0.01)
Total	Energy	428.62	100.00	36.64	13.38
	(Exergy)	(395.68)	(100.00)	(34.14)	(12.61)

In the following subsections, the utilization of renewables energy and exergy in these subsectors during 2001 is analyzed.

5.1. Utility sector

The two main electricity generation sources in Turkey are hydropower and fossil fuels including petroleum, lignite, hard coal and natural gas. In addition, electricity is generated from thermal and renewable sources (biomass, geothermal, wind). The only operating geothermal power plant of Turkey is the Kizildere geothermal power plant with an installed capacity of 20.4 MW_e, located near the city of

Table 4
Energy and exergy utilization values for Turkey's renewables by subsector in 2001

Subsectors	Distribution of renewable energy sources (RESs) (PJ)						Total (PJ)	Share of RESs in subsectors (%)
	Biomass	Wood	Geothermal	Solar	Wind	Hydro power		
Residential–commercial	54.05 (56.75)	203.94 (214.13)	60.32 (17.41)	8.11 (7.54)			326.42 (295.82)	39.95 (38.12)
Industrial				2.21 (2.06)			2.21 (2.06)	0.24 (0.26)
Utility	1.62 (1.70)		3.20 (0.93)		0.23 (0.23)	94.94 (94.94)	99.99 (97.80)	9.04 (8.76)
Total	55.67 (58.45)	203.94 (214.13)	63.52 (18.34)	10.32 (9.59)	0.23 (0.23)	94.94 (94.94)	428.62 (395.68)	13.38 (12.61)

Exergy values are given in parentheses.

Denizli in Western Anatolia [29]. Up to date, three wind power plants were installed with a total capacity of about 18.9 MW_e [26].

As indicated in Table 5, there was totally 1105.68 PJ of energy and 1116.86 PJ of exergy inputs to the utility sector for electricity production in 2001 and these values decreased about 5% in 2000. In 2001, produced electricity provided was 80.25% fossil-fired and 19.55% hydropower, while the contribution of the different renewable resources in the same year was as follows: 0.04% geothermal, 0.06% wind and 0.10% biomass.

First and second law efficiencies of renewables for the utility sector (ϵ_1 and ϵ_2) were calculated from the following equations, respectively [8]:

$$\varepsilon_1 = \left(\frac{W_{\text{out}}}{\delta H}\right)100 \tag{1}$$

$$\varepsilon_2 = \left(\frac{W_{\text{out}}}{W_{\text{in}}}\right)100 \tag{2}$$

Using the numerical values, we found $\varepsilon_1 = 87.26\%$, and $\varepsilon_2 = 89.21\%$ in 2001 for the utility sector. Energy and exergy efficiencies of the total energy source input to the utility sector were determined by using the same equations given above. These values were obtained to be 39.95% and 39.55%, respectively. These figures have indicated that there is a considerable difference between the values for the total and the renewables.

It should be noticed that there is no significant difference between energy and exergy utilization efficiencies. To estimate the overall first and second law efficiencies for the utility sector in Turkey, it is necessary to add transmission and distribution losses to the generation losses. Transmission and distribution losses

Table 5
Utilization of renewables energy and exergy in the conversion sector in 2001

Type of RESs		Input energy	Percentages*		Electricity produced		
		(PJ)	R	S	(PJ)	(%)	ε_1 (ε_2)
Biomass	Energy	1.62	2.91	0.15	0.39	0.45	24.09
	(Exergy)	(1.70)	(2.91)	(0.15)			(22.94)
Hydropower	Energy	94.94	100.00	8.59	86.31	98.92	90.91
	(Exergy)	(94.94)	(100.00)	(8.50)			(90.91)
Geothermal	Energy	3.20	5.03	0.29	0.09	0.37	10.01
	(Exergy)	(0.93)	(4.98)	(0.08)			(34.50)
Wind	Energy	0.23	100.00	0.02	0.23	0.26	100.00
	(Exergy)	(0.23)	(100.00)	(0.02)			(100.00)
Renewables	Energy	99.99	44.50	9.04	87.25	19.75	87.26
total	(Exergy)	(97.80)	(53.77)	(8.76)			(89.21)
Total input	Energy	1105.68			441.72		39.95
	(Exergy)	(1116.86)			(441.72)		(39.55)

*R, resource; S, sector.
Exergy values are given in parentheses.

within the utility sector were found to be 22.43 and 22.65% of all-electrical energy produced in 2001 [46]. This assumption results in the following figures: $\varepsilon_1 =$ 31.16% and 68.06%, and $\varepsilon_2 = 30.84\%$ and 69.58% for the total and renewables energy inputs to this sector in 2001, respectively.

5.2. Residential–commercial sector

This sector includes the residential and commercial public activities. The specific applications for energy and exergy consumptions were determined for 2001. About 34.48% of the final energy consumption was used in this sector in 2001 [20]. The highest contributions came from solid biomass (wood) with 203.94 PJ in the 2001, as illustrated in Table 4. However, geothermal use has continuously increased for space heating with 60.32 PJ. In addition, utilization of RE is spreading in this sector, especially from sunlight for water heating with 8.11 PJ, and from biowaste for general usage with 54.05 PJ.

The overall efficiency and effectiveness values for renewables uses in the Turkish residential–commercial sector in 2001 were estimated as follows:

5.2.1. Space heating

Based on the values obtained from Turkey's population census, the fuel preferences of dwelling units for space heating were determined for each province, while energy consumption in residences were predicted according to geographical regions and selected provinces in 1998 in Turkey [47]. The distribution of heating systems according to their utilization ratios in 1998 was as follows: district heating at 2.50%, central heating at 5.30%, individual heating at 4.30%, stove at 84.10% and others 3.80%. It is considered that stoves have been widely used for heating purposes even in 2001 with 83.20% according to Ref. [47].

Heating by stoves is partial heating. Stoves consume less fuel compared to other central heating system. Although they have an advantage for energy economy, for human health and comfort it is not the preferred system.

In a study performed by Aycik et al. [48], thermal efficiencies of coal- and wood-fired stoves used in Turkey were found to be on average 45 and 35%, respectively. Besides this, according to the Turkish Standard (TS 4900), the thermal efficiencies of coal-fired stoves should be greater than 70% [49]. The second law efficiency of space heating was calculated from the equation

$$\varepsilon_2 = \left(\frac{\varepsilon_1}{q_f}\right)\left\{1 - \left[\frac{T_o}{T_2 - T_0}\right]\ln\left(\frac{T_2}{T_0}\right)\right\} \quad (3)$$

where ε_1 is the first law efficiency, q_f is the fuel factor, T_o is the reference temperature and T_2 is the temperature of the space heating equipment.

Forty-eight percent of all fuel input to the residential–commercial sector was for space heating, which is done entirely by home heaters having the same first law efficiencies of home stoves. It is assumed that a fuel with $q_f = 0.99$ is fired, the supply temperature for the space heating equipment is 50 °C and the ambient temperature

is 20 °C [10,11]. Using Eq. (3), the numerical values and the first law efficiencies assumed, we found ε_2 for energy carriers of space heating, as given in Table 6.

Overall first ($\varepsilon_{1,\mathrm{oc}}$) and second law ($\varepsilon_{2,\mathrm{oc}}$) efficiencies of each component such as space heating, water heating, cooking, etc., were calculated as follows:

$$\varepsilon_{1,oc} = [(a_1 * \varepsilon_1) + (a_2 * \varepsilon_2) + (a_3 * \varepsilon_3)]/100 \quad (4a)$$

$$\varepsilon_{2,oc} = [(a_1 * \varepsilon_1) + (a_2 * \varepsilon_2) + (a_3 * \varepsilon_3)]/100 \quad (4b)$$

where a denotes the share of renewables in the total of each component. These values are obtained from Table 4.

Substituting the relevant numerical values into Eqs. (4a) and (4b), we obtained $\varepsilon_{1\mathrm{rc,sh}} = 38.87\%$ and $\varepsilon_{2\mathrm{rc,sh}} = 2.66\%$ in 2001 for space heating, respectively.

5.2.2. Water heating

In 2001, 32% of all direct fuel use was for water heating. The distribution of residences according to their types of heating systems in 2001 was as follows: stove with 33.6%, solar collector with 10.1%, thermo siphon type heater with 7.8%, gas or LPG fuelled water heater with 42.6%, combined heater with 4.6% and central hot water system 1.3% [47]. These figures indicate that a small part of Turkey's solar energy potential is used for water heating, although Turkey has a huge solar energy potential. First law efficiencies of direct fuel and solar collector use for water heating are assumed to be 27.40%, respectively [11,12]. The second law efficiency of water heating was calculated from Eq. (3). It is assumed that hot water and ambient temperatures are 60 °C and 20 °C, respectively, while q_f is 0.99 for direct fuel uses. Substituting the relevant numerical values into Eq. (3), we obtained ε_2 values ranging from 3.10 to 10.80% for all energy carriers, and $\varepsilon_2 =$ 4.5% for solar collector, 3.4% for wood and 3.1% for animal waste.

Using Eqs. (4a) and (4b) and the numerical values assumed, we found renewables first and second law efficiencies $\varepsilon_{1\mathrm{rc,wh}} = 29.23\%$, and $\varepsilon_{2\mathrm{rc,wh}} = 3.69\%$ in 2001 for water heating, respectively.

5.2.3. Cooking

In cooking activities, various fuels such as natural gas, city gas, LPG, wood, etc., are used. 20% of all direct fuel use was for cooking. The first law efficiencies are obtained from Ref. [47], while the cooking and ambient temperatures are assumed to be 120 °C and 20 °C, respectively [11].

The second law efficiencies were calculated by the following equation

$$\varepsilon_2 = \varepsilon_1 \left[1 - \left(\frac{T_0}{T_2}\right)\right] \quad (5)$$

Using Eq. (5), these assumptions yield second law efficiencies of fuel use with a range of 4.1–17.2% for the year studied.

Overall first ($\varepsilon_{1\mathrm{rc,co}}$) and second law ($\varepsilon_{2\mathrm{rc,co}}$) efficiencies were calculated from Eqs. (4a) and (4b) in a similar way and were found to be 21.14% and 4.33% for cooking in 2001, respectively, as indicated in Table 6.

Table 6
Energy and exergy utilization efficiency values for Turkey's renewables and total in 2001 (%)

Subsector		Biomass		Wood		Geothermal		Solar		Wind		Hydropower		Total	
		ε_1	ε_2	ε_1	ε_2	ε_1	ε_2	ε_1	ε_2	ε_1	ε_2	ε_1	ε_2	ε_1	ε_2
Residential–commercial	Space heating	35.00	2.50	35.00	2.50	55.00	5.33							38.87	2.66
	Water heating	27.00	3.10	30.00	3.40			30.00	3.90					29.23	3.69
	Cooking	20.00	4.10	22.00	4.50									21.14	4.33
	Subtotal	34.36	2.58	34.96	2.53	55.00	5.33	30.00	3.90					38.44	2.75
Industrial								30.00	3.90					30.00	3.90
Utility		24.09	22.94			10.01	34.50			100.00	100.00	90.91	90.91	87.26	89.21
Renewables total		34.06	3.02	34.96	2.53	52.73	6.81	30.00	3.90	100.00	100.00	90.91	90.91	49.86	24.14
Turkey total														44.99	25.22

Overall first and second law efficiencies for renewable use in the whole residential–commercial sector were calculated by the following equations:

$$\varepsilon_{1,orcs} = [(r_{sh} * \varepsilon_{1sh,o}) + (r_{wh} * \varepsilon_{1wh,o}) + (r_{co} * \varepsilon_{1co,o})]/(r_{sh} + r_{wh} + r_{co}) \tag{6}$$

$$\varepsilon_{2,orcs} = [(r_{sh} * \varepsilon_{2sh,o}) + (r_{wh} * \varepsilon_{2wh,o}) + (r_{co} * \varepsilon_{2co,o})]/(r_{sh} + r_{wh} + r_{co}) \tag{7}$$

where r denotes the renewable use by the residential–commercial sector in energy terms.

Substituting the relevant numerical values into Eqs. (6) and (7), we obtained $\varepsilon_{1,\mathrm{orcs}} = 38.44\%$, and $\varepsilon_{2,\mathrm{orcs}} = 2.75\%$ in 2001 for renewable energy use in this sector, as shown in Table 6.

5.3. Industrial and transportation sectors

Of the Turkish total energy input in 2001, the industrial sector accounted for 36.60%. This sector consumed about 2.21 PJ of solar energy in Turkey, as illustrated in Table 4. Energy and exergy efficiencies of solar were $\varepsilon_{1\mathrm{b}} = 30\%$ and $\varepsilon_2 = 3.90\%$ in this sector, while the transportation sector had no uses in terms of renewables in Turkey.

6. Results and discussion

In this study, energy and exergy utilization efficiencies of renewables in 2001 were analyzed for the Turkish subsectors, as well as for Turkey's general. The energy and exergy inputs were also compared, while loses and efficiencies were identified. Based on the estimations in energy-exergy consumptions, it is expected that annual RE utilization in the TPES will increase from 2001 to 2010.

Table 7 illustrates the main outcomes of the energy and exergy utilization analysis for both Turkey's general and renewables. It is clear from this table that the energy efficiencies for Turkey's general are in the range of 41.40 to 44.99%, while the exergy efficiencies vary from 21.83% to 27.10%. For Turkey's renewables, energy and exergy efficiencies are found to be 49.86% and 24.14%, respectively. All subsectors studied showed considerably important and comparable loses of energy. The industrial sector constituted the biggest energy loss, followed by the residential–commercial and utility sectors.

In terms of exergy loses, the sectors ranked rather differently. The residential–commercial sector accounted for about 97% of all exergy loses, followed by the industrial and utility sectors, as shown in Table 6. These results indicated the need of saving the use of energy and to improve habits of energy use in this sector and its subsectors.

Turkey has major potential for energy efficiency improvements. Exploitation of this potential could reduce environmental emissions and improve security of supply. The potential for renewables is also significant. In recent years, progress has been made in both fields. New energy efficiency legislation and regulations are under preparation that will go some way towards using this potential.

Table 7
Comparison of total energy and exergy inputs/outputs as well as energy and exergy utilization efficiencies of Turkey's renewable and total

Investigators	Year analyzed/ published	Population	Total energy (exergy) input		Total energy (exergy) ouput		Renewables energy (exergy) input[a]		Renewables energy (exergy) ouput		Efficiencies ε_1 , (ε_2)	
			(PJ)	(GJ/capita)	(PJ)	(GJ/ capita)	(PJ)	(GJ/ capita)	(PJ)	(GJ/ capita)	Total (%)	Renewables (%)
Unal [8]	1991/1994	57,024,515	2275 (2279)	39.9 (39.97)	1029.5 (539.5)	18.05 (9.46)	434.16 (450.54)	7.61 (7.90)			45.30 (23.70)	
Rosen and Dincer [10]	1993/1997	58,808,625	1645.2 (680.6)	27.98 (11.57)	680.6 (445.2)	11.57 (7.57)	440.31 (455.1)	7.49 (7.74)			41.40 (27.10)	
Ileri and Gurer [11]	1995/1998	59,706,545	2695.2 (2697.3)	45.14 (45.17)	938.9 (352.3)	15.73 (5.90)	(463.9) (474.4)	7.77 (7.95)			34.90[b] (13.10)	
Utlu and Hepbasli [16]	1999	66,022,636	3391.66 (3380.34)	51.37 (51.20)	1153.46 (499.61)	17.47 (17.55)	448.99 (459.25)	6.80 (6.96)			43.24 (24.04)	
	2000	67,803,927	3527.33 (3469.62)	53.42 (52.55)	1250.03 (525.77)	18.93 (7.96)	482.89 (449.72)	7.12 (6.63)			44.91 (24.78)	
Present study	2001	68,820,985	3203.22 (3139.07)	46.54 (45.61)	1442.35 (783.75)	20.96 (11.39)	428.62 (395.68)	6.23 (5.75)	213.71 (95.51)	3.10 (1.38)	44.99 (25.22)	49.86 (24.14)

Exergy values are given in parentheses.
[a] These values are found by calculation from Refs. [8,10,11,16].
[b] Excluding utility sector use. These values are obtained to be 43.61 (21.83)% with the utility sector use of 236.6 PJ [16].

7. Conclusions

The use of exergy tools in order to analyze resource conversion systems is gaining in popularity among scientists and engineers, as well as in the community at large [50]. In this study, using a method proposed by Rosen and Dincer [20], who applied Reistad's approach [22] with several minor differences, Turkey's energy and exergy utilization efficiencies were analyzed for the RESs. These efficiency values obtained for Turkey were also compared to those reported by other investigators.

This study indicated that exergy utilization in Turkey was even worse than energy utilization. In other words, Turkey represents a big potential for increasing the exergy efficiency. It is clear that a conscious and planned effort is needed to improve exergy utilization in Turkey. Considering the existence of energy-efficient technologies in the world, the major problem is delivering these technologies to consumers or, in other words, using effective energy-efficiency delivery mechanisms and implementing active energy conservation programs, which are vital for sustainable development, as reported in detail elsewhere [51,52].

The government of Turkey should also continue to address deforestation problems, create a level playing field for renewables by allowing prices of conventional fuels to rise to market levels and give priority to the most cost-effective projects when supporting renewables, as recommended by the International Energy Agency [53].

It may be concluded that the analyses reported here will provide the investigators with knowledge about how effective and efficient a country uses its RESs. This knowledge is also needed for identifying energy efficiency and/or energy conservation opportunities, as well as for dictating the energy strategies of a country or a society.

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